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FEASIBILITY OF VIBRATION ANALYSIS AS A PREDICTIVE MAINTENANCE TOOL ON HEATING, VENTILATION, AND AIR CONDITIONING EQUIPMENT IN U.S. AIR FORCE MEDICAL FACILITIES

By

JON W. YOW

A THESIS PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BUILDING CONSTRUCTION

UNIVERSITY OF FLORIDA

1998

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, for a thesis for the degree of Master of Science in Building Construction.

Paul Oppenheim

Paul Oppenheim, Chair
Associate Professor of Building Construction

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, for a thesis for the degree of Master of Science in Building Construction.

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This thesis was submitted to the Graduate Faculty of the College of Architecture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Master of Science in Building Construction.

May, 1998

R. Wayne Drummond

Dean, College of Architecture

Dean, Graduate School

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GLOSSARY

Acceleration	The rate of change of speed, usually measured in G's (32 ft/sec2), the force created when the vibrating object starts and stops each motion.
Accelerometer	A transducer that collects vibration information.
Amplitude	The amount or severity of a vibration. Amplitude is measured in displacement (mils), velocity (ips), or acceleration (Gs).
Balancing	Adjusting the mass centerline of rotating equipment to match the geometric centerline
Base Civil Engineering (BCE)	Military agency that manages construction, engineering, and maintenance services to all military agencies on an installation
Critical Speed	Rotating speed that corresponds with the natural frequency of the assembly. Typically associated with high amplitude readings
Differentiation	Mathematical operation that converts a displacement to velocity, or velocity to acceleration. It is performed electronically on an analog signal or can be performed digitally on a spectrum
Displacement	Distance a machine travels as it vibrates. Used for monitoring equipment rotating slower than 600 revolutions per minute
Fast Fourier Transform (FFT)	Equation used to calculate and depict amplitude as the vibration spectrum
Frequency	The repetition rate of an event per unit of time. Measured in revolutions per minute (RPM), cycles per minute (CPM), and cycles per second (Hertz)
Harmonic	An integer multiple of a specified frequency
Integration	Mathematical operation that converts an acceleration reading to velocity, or velocity to displacement.
Mils	Unit of measure for displacement (thousandths of an inch). Usually measured in mils peak to peak to represent total displacement.
Natural Frequency	The frequency at which free vibration (resonance) exists

Phase Reference	A reference signal generated by a strobe light observing an event every revolution. Used to measure phase relationships to other measurement points and determine the points of adjustment
Resonance	Condition where vibration levels increase dramatically because an object is vibrating at its own natural frequency
Spectrum	A graphical representation of frequencies and their amplitudes using FFT. Used to diagnose problems and trend condition of machinery.
Transducer	Any device that translates the magnitude of one quantity into another quantity. The accelerometer, velocity transducer, and eddy current probe are the most common transducers used in vibration measurements.
Velocity	The speed of movement, measured in inches per second
Vibration	A periodic motion of the particles of an object in alternately opposite directions from the position of equilibrium.

Abstract of Thesis Presented to the Graduate School
Of the University of Florida in Partial Fulfillment of the requirements
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By

Jon W. Yow

May 1998

Chair: Paul Oppenheim
Major Department: M.E. Rinker Sr., School of Building Construction

Health care costs have dramatically risen over the last 10 years and there are persistent requests by administrators and government officials to keep these costs under control. As the overall health care costs have risen, there has been increasing demand to keep facilities costs low. The United States Air Force (USAF) Medical Service is suffering from reductions of funds and maintenance personnel for their facilities. Some military administrators have found it necessary to divert funds from maintenance to support other programs. To ensure the reliability of our mechanical systems for climate control and a quality indoor environment, the USAF medical service must make a paradigm shift in its maintenance strategy. This report addresses the feasibility of using vibration monitoring as a predictive maintenance tool to assess the condition of equipment, develop new preventive maintenance plans, and reduce the number of breakdowns that impact operation of facilities.

CHAPTER 1
INTRODUCTION

The four basic approaches to equipment maintenance are reactive maintenance, preventive maintenance, predictive maintenance, and pro-active maintenance. A well-developed maintenance philosophy will address and encompass all these approaches in establishing the optimum maintenance program.

Reactive maintenance is based on the philosophy of repair or replace after failure, and is known as reactive or emergency maintenance. This is adequate for inexpensive and non-critical equipment; however, using this method for critical or expensive equipment has proven to be the most disruptive and least cost effective strategy.

Preventive maintenance (PM) is also known as time-interval maintenance, scheduled maintenance, and time-based maintenance. It is based on calendar time or equipment running hours. Intervals are based on the worst, or the average time to failure, as reported by the manufacturer or on operator experience. If intervals are based on the anticipated worst case, the maintenance performed will be redundant and result in unnecessary repairs or replacements. However, if maintenance is based on the average deterioration rate. some reactive maintenance and breakdowns must be accepted. In either case, the preventive maintenance program has some inherent inefficiency.

Predictive maintenance programs are based on periodic or constant monitoring the condition of the equipment. It is also known as condition-based and performance-based determine the level of maintenance required and discover problems before the possibility of breakdown, thereby eliminating redundant maintenance, reactive maintenance, and reducing breakdowns. Predictive maintenance techniques monitor deterioration, processing conditions, and specific events that precede the development of equipment faults or failures. Unlike physical inspection techniques normally used in PM, condition monitoring provides information about the component or system without requiring shutdown and dismantling which can sometimes introduce defects in efficiently operating equipment. In the late 1970s, preventive maintenance based on mean time to failure data was referred to as predictive maintenance and for this reason, there still exists some confusion of the definition of predictive maintenance.

Pro-Active maintenance is based on taking predictive maintenance one step further and is known as reliability or productive maintenance. Pro-Active maintenance is a strategy where maximum equipment operating time and availability are achieved through precision installations, precision repair requirements, training, and root cause failure analysis. Root cause failure analysis, requires that you always determine the answer to the question "Why did this equipment fail?" Once this question is answered, long term solutions can be implemented. Precision installation, precision repair, and training are maintenance practices designed to prevent failures before they occur. The first step in moving toward a pro-active maintenance program is to effectively implement both preventive and predictive maintenance techniques.

Statement of Problem

The United States Air Force (USAF) Medical Service is suffering from reductions of funds and maintenance personnel for their facilities. Health care costs have dramatically risen over the last 10 years and there is constant pressure by administrators and government officials to keep health care costs under control. Health care facilities are not immune from cost control methods, meaning many facilities have found their budgets cut, and some military administrators have even found it necessary to divert dollars from facility programs to provide certain medical services. No one questions that the medical services are more important than the facility or that they may have a higher return on investment; however something must be done to ensure these facilities remain in operational condition.

Efficient use of maintenance dollars is demanded in these facilities more than ever. For this reason, there have been many efforts over the last ten years to standardize and revamp the existing preventive maintenance programs throughout all the facilities. These efforts have proven successful and the improvements have resulted in the increased levels and quality of the preventive maintenance performed. However, these efforts are directed at the symptoms of the problems, and not at the root cause.

Failures that cause a high impact on the operation of the facility and the ability to provide services are referred to as catastrophic failures. There have been several catastrophic failures in the past, which have temporarily caused facilities to reduce or even eliminate some services until corrective actions were accomplished. While reducing maintenance costs is a major objective of all medical facilities, an even more critical objective is the reduced impact to services caused from equipment failure.

The heating, ventilation, and air conditioning (HVAC) system in a healthcare facility is one of its most important systems. Not only does the HVAC system provide a comfortable environment, but in a health care facility, the HVAC system is essential to introduce filtered fresh air at the high volumes necessary to meet sanitary requirements and to control humidity. For this reason, the HVAC system is intensively designed with maximum redundancy. This redundancy, however, has led to the apathetic approach taken with maintenance over the years, as a failure in a redundant system causes minimal disruption. The additional costs of redundant equipment, though, including their maintenance, operating costs, and life expectancy, substantially impact the overall cost of providing healthcare. While redundant systems may appear a necessity, modern pro-active maintenance systems can reduce much of the risk in operating a non-redundant system thereby allowing considerable cost savings.

In the last three years there has been an increasing number of reports linking disease and sickness to the quality of the air inside the building, but no study has proven the direct relationship between the spread of infection in a healthcare facility and its air quality. The quality of the air distribution system and standards for design of systems have continued to increase in an attempt to contain the problem, causing even more expensive redundant systems in an era of decreasing budgets. While the risk of the spread of infection outweighs any cost savings achievable through lowering HVAC standards, eliminating redundancies through pro-active maintenance practices can dramatically decrease overall HVAC costs.

Objective of Study

The objective of this study is to evaluate vibration analysis as a predictive maintenance tool and determine if implementing it for HVAC systems in USAF Medical Facilities would be cost effective. The evaluation will address reasons for implementation, the issues of implementation costs, monitoring equipment, potential cost savings, availability of contracting services, and technical expertise required. The study will only consider rotating equipment such as fans and motors of the HVAC system.

For predictive maintenance to be an effective tool there must be a potential for cost savings. Industry has accepted that proper use of condition monitoring will extend the useful life of machinery and provide information that can locate problems before they threaten the operation of the machinery. The questions that still arise relate to verifiable cost savings. An economic analysis of the cost required to implement various levels of vibration analysis will determine the most effective level for the U.S. Medical Service.

Possible Conclusions

Possible Conclusion #1: Vibration analysis is not cost effective for U.S. Air Force medical facilities.

Possible Conclusion #2: The potential return on investment in vibration analysis fully justifies immediate implementation in all US Air Force Medical Facilities.

Possible Conclusion #3: Vibration analysis is effective, but the marginal potential for return on investment determines that it should only be considered for newly constructed facilities.

Possible Conclusion #4: Vibration analysis is only warranted for expensive and critical equipment and used in conjunction with preventive maintenance practices.

Possible Conclusion #5: Vibration analysis should be included in the statement of work for all contract maintenance.

Possible Conclusion #6: If Vibration analysis is successful, will it have an impact on the design of future health care facilities.

Research Limitations

The main research limitation on this project was the inability to witness the vibration analysis programs at a larger sampling of medical facilities. This required some of the comparative analysis portion of this study to be based on case studies reported by other individuals. The research was further limited to the lack of documentation showing costs associated with the catastrophic breakdowns throughout both study groups. The only medical facilities located that were using vibration analysis were all being maintained by the same firm, Tampa Armature Works (TAW) Engineering. All facilities are using a similar scope of work and the main differences in their programs are the amount and efficiency of their preventive maintenance program.

The second critical limitation was defining a cost base to provide comparison. Not all medical facilities use the same accounting methods to track their cost expenditures on maintenance. This fact made it difficult to establish a benchmark for comparison between facilities and to determine the exact direct cost savings for facilities. To account for the different maintenance philosophies and the accounting measures, a comparison was performed using the ratios of expenditures within different categories of maintenance. This provides a more accurate comparison of the programs than looking at the direct costs. The analysis of the data assumes that the information provided is accurate and representative of the remainder of the facilities. These assumptions provide a margin of error to the analysis. The conclusions consider this subjectivity and use the calculations that are most critical to implementing a vibration monitoring program.

Case studies located throughout the literature search provided cost savings from vibration monitoring programs that could not be considered totally objective. Many of these case studies reported estimated costs for run to failure scenarios' of equipment based on assumed failure rates. Since there is no guarantee that the equipment would fail at this arbitrary time, this is not an acceptable comparison. Many case studies; however, were dedicated to the cost savings from one particular piece of equipment. Of the units in the case studies, many had failed in the past and the cost required for emergency replacement along with equipment downtime was well documented. Avoidance of these costs is a justifiable cost saving.

Many predictive maintenance programs are using two or three condition monitoring techniques to offset their reduced levels of preventive maintenance. This provides justifiable cost savings if there is no increase in breakdowns and the overall costs of the program are reduced. However, the health care facilities studied were using vibration analysis only on critical and high-speed equipment. Vibration analysis is being used as an additional tool to discover problems with machinery at an early stage before a breakdown occurred. The facilities are not reducing their preventive maintenance requirements and vibration analysis is an additional part of their maintenance strategy.

Economic justification is difficult since medical facilities are using vibration analysis mainly to identify emerging problems to avoid equipment failure. The majority of the justification rests in the intangible costs associated with providing a healthy environment for patients and staff. The cost associated with the avoidance of maintenance are significant, but are not easily or objectively quantified.

CHAPTER 2
LITERATURE REVIEW

Introduction

Vibration Monitoring has been used in design and production of most types of mechanical machinery for many years. Vibration Monitoring as a part of a maintenance strategy has been on the rise the last ten years with the development of computer technology. Vibration monitoring would not be effective without the microprocessor and the ability to do the enormous amount of calculations required for analysis. This report discusses the basics of vibration monitoring, its benefits, and methods for its implementation. The analysis of vibration data, spectral analysis, and troubleshooting techniques of vibration problems exceed the scope of this report and will not be discussed beyond their impact on implementation and cost savings.

R. Keith Mobley in *An Introduction to Predictive Maintenance* describes the need for predictive maintenance programs in facilities with the following.

> Recent surveys of maintenance management effectiveness indicate that one third of all maintenance costs is wasted as the result of unnecessary or improperly carried out maintenance. This represents a loss of more than 60 billion dollars each year. . . . The dominant reason for this ineffective management is the lack of factual data that quantifies the actual need for repair or maintenance of plant machinery, equipment, and systems. Maintenance scheduling has been and, in many instances, is predicated on statistical trend data or on the actual failure of plant equipment. (Mobley, An Introduction to Predictive Maintenance, 1990, p. 1)

An initial search was done on the Internet and within the University of Florida Library System to determine what information was available on Vibration Analysis. There was little information available from the Library that was applicable to this study. Almost all information through mechanical engineering and HVAC texts related to vibration dealt with the attempt to control noise transmitted to the occupied areas of facilities. Only the 1993 U.S. Corps of Engineers Technical report titled, *"Vibration Monitoring for Predictive Maintenance in Central Energy Plants"* was germane. This study recommended use of vibration analysis for all critical equipment and the majority of the report detailed how to implement a vibration monitoring program and specific analysis techniques.

In the spring of 1997, the Internet search provided 10 companies providing the service and two training organizations. The amount of information available for research was very limited. The majority of the initial investigation was done through books purchased from the Vibration Institute and information provided by Tel-A-Train, both of whom specialize in training on equipment condition monitoring. As time progressed, the Internet became a primary source of information and an introduction to people involved in the field of vibration analysis. Later Internet searches performed in December 1997 provided over 100 potential contacts and information sources.

An initial literature review was performed to obtain an understanding of the maintenance process and the differences between the most common maintenance strategies. At the same time, information was reviewed on the current problems of medical facilities dealing with indoor air quality. Due to the problems associated with indoor air quality in hospitals and the critical nature of HVAC equipment in medical facilities, a decision was made to concentrate this study on the benefits of vibration analysis in maintaining HVAC equipment.

Indoor air quality in health care facilities is quickly becoming a topic of discussion and controversy. The Joint Commission for Accreditation of Hospitals (JCAHO) strongly suggests health care facilities have an IAQ program to insure a healthy environment. In implementing an IAQ compliant program, Wayne Hansen suggests in the January 1998 issue of *Health Facilities Management Journal* that constant ventilation is a key to the quality of indoor air by stating:

> Ensure that all HVAC and exhaust systems are operating during all hours of occupancy. This step primarily refers to medical office buildings and other non-critical care patient areas that do not require 24-hour operation, where evening shutdown of the HVAC system may occur. For evening operation or janitorial activities, boilers and chillers may be set back or shut down, but ventilation must remain active. (p. 23)

An essential aspect in maintaining a healthy, healing environment is the control of relative humidity. Relative humidity (RH) varies with temperature and the amount of water vapor in the air. RH is important because it plays a role in individual comfort. If RH levels exceed 70 percent, then bacteria, fungus, yeast, and mold growth can occur in air ducts, heat exchangers, and on other exposed surfaces. These growths have been found in the ductwork of facilities and are the reason for many agencies instituting duct cleaning standards and requirements. If RH levels are low, 10 to 20 percent, burning eyes and dryness in the nose and throat can result. According to ASHRAE 55-1981, RH levels should be maintained, whenever possible, between 40 and 55 percent for comfort purposes; however, 30 to 55 percent is tolerable for most individuals.

All of these issues can be interpreted to mean any reduced ventilation, whether caused deliberately or accidentally, affects the quality of the indoor environment. In the "Economic Consequences of Poor IAQ", *Facilities Management Journal, September/October 1997*, Sten Olaf Hansen states that studies by the National Energy Management Institute (NEMI) in 1994 reported workers' productivity changed by 1.5 to 6 percent when the IAQ level of a facility changed. The levels were described as a healthy, generally healthy, unhealthy – source unknown, unhealthy – source known, and suffering from sick building syndrome or experiencing building related illness. A healthy facility that experiences a loss of HVAC service (unhealthy – source known) would be affected by a 4.5% reduction in productivity. If the average employee cost is assumed to be $100 per day, then the impact to labor cost can be estimated as $4.50 per day for each employee. While this does not appear to be a dramatic cost, it does have a substantial impact when multiplied by 300 employees and shows a cost of $1350 per day. If the equipment is out of service for one week, then the lost productivity attributed to the HVAC system can be estimated as $ 6,750.

Vibration Monitoring Overview

HVAC motors and fans constructed up until the early 1970s usually had very high mass that provided substantial damping of vibration forces. Since the vibrations sources were often small in magnitude, the vibration levels of these highly damped machines was relatively low. However, with the development and use of strong lightweight materials in

HVAC equipment, the mass of machines has decreased and the level of vibration has increased. With the increase in vibration has come the associated problems of noise and vibration related problems. The demands made on HVAC equipment performance and reliability are constantly increasing.

Sometimes it may be necessary to reduce the vibration of an existing machine because of inadequate initial design, a change in function of the machine, or a revision of acceptable noise levels. Techniques for the analysis of vibration in dynamic systems used in the design process are also applicable to existing systems. Similar problems of vibration or noise are detected by the same analytical methods regardless of whether the machine is existing or being designed, but the corrective actions may be different.

Equipment maintenance and unexpected downtime resulting from equipment failure can make up a significant part of the cost of running a facility. Unexpected downtime of HVAC equipment in a medical facility can be even more costly. Cancelled medical procedures and the lost of productivity and inconvenience can result in an even higher cost than the cost to repair the machinery and damage the reputation of the medical facility itself.

Vibration analysis uses electronic hardware and software to monitor vibration trends and to distinguish between normal vibration signals and those indicating problems in equipment operation. Vibration Analysis is a non-intrusive diagnostic tool used in a variety of levels throughout the industry. It may be used to only locate problems with machinery or it can be used to troubleshoot, fine tune, and predict operational problems with machinery. Vibration analysis is rapidly becoming standard practice in most industrial predictive maintenance programs and appears to be the most widely accepted method overall.

Since vibration analysis is a tool that predicts component failure, those parts identified as needing corrective action are scheduled for repair or replacement during planned shutdowns, rather than during costly emergency outages that are a result of equipment failure. Vibration analysis can also be used as a tuning device for all rotating equipment and as a way to diagnose and reduce machine inefficiencies, thus reducing operating cost and energy utilization. Properly aligned and balanced equipment performs more efficiently and uses less energy.

Vibration

Vibration is a rapid, periodic, oscillation of an object. The vibration occurring in most machines is undesirable because the dynamic stresses influence fatigue and failure of the machine, cause energy losses, reduce its performance, and produce excessive noise that can be transmitted to habitable spaces. HVAC motors and fans, like most rotating equipment, suffer from the effects of vibration. Some vibration is unavoidable, but excessive vibration must be minimized before it can lead to premature deterioration of equipment components and eventually result in failure of the unit. Vibration analysis of machines, therefore, is often a necessary prerequisite for controlling not only vibration, but also energy usage and noise.

A review of the basic terms and definitions in vibration is given in the glossary.

Vibration Monitoring

Vibration level in equipment directly impacts its efficient performance and life expectancy. It is essential to minimize vibration levels in order to realize effective life cycle cost management of the equipment.

Computational Systems Inc., which sponsors the Preventive Maintenance Program of the Year Award, stated that in 1990, approximately 35% of all U.S. industrial companies had implemented a predictive maintenance strategy that used some form of condition monitoring. Vibration monitoring was the predominate method used by 99% of the companies followed by oil analysis and infrared thermography. Computational Systems reported that well documented programs reported savings of over ten dollars per dollar spent, yielding a ten to one savings to cost ratio.

Vibration can sometimes be subtle. A mechanic may visually inspect a piece of running machinery and not detect any significant vibration, but by touching the same piece of running equipment a definite periodic vibration can be felt. Even lesser vibrations can be detected by holding a metal tool against the piece of running machinery and listening closely for any sounds made as the tool bounces against the machine casing. Additional resources assist the mechanic in locating less obvious sources of vibration, which could adversely affect the life of the equipment.

If a newly installed piece of equipment obviously vibrates erratically, the mechanic assumes that, without correction, the machine will probably fail in a relatively short period. The mechanic will tune the equipment to run smoother and more efficiently by making adjustments. Decreasing excessive vibrations provides less wear on the individual parts of the equipment, increases the operating efficiency, reduces energy consumption, and increases the chance for a longer life expectancy of the equipment.

Modern vibration monitoring equipment can improve maintenance personnel's ability to recognize problems and prevent machinery breakdown. Just as the mechanic used the metal tool to reveal vibrations invisible to the visual inspection, modern technicians can use improved resources in data collection and analysis to estimate the condition of the equipment.

The fundamental element of a vibration analyzer is the transducer or probe. The probe contains the accelerometer, which converts vibration into an electronic signal, which can be analyzed by the computer software. This transducer consists of a spring mass system (with a damping factor of virtually zero) which, under the influence of acceleration, generates a force that presses against a piezoelectric crystal. These crystals (such as quartz or barium titanate) allow accurate measurement of vibration frequencies up to 3000Hz.

To ensure higher accuracy in the measured vibration data, readings should not be taken while a machine is operating at or near resonance. Resonance is a condition that arises when a machine is being operated at or near its natural frequency. Any measurement taken while a machine operates at or near resonance will contain large errors in the vibration amplitude data.

There are two principal methods of displaying vibration signals, time domain and frequency domain. Time domain (figure 1) is a two dimensional display in which amplitude appear on the vertical axis and time on the horizontal. Both the oscilloscope trace and the familiar vibration meter output are examples of time frequency displays of a vibration signal. The frequency domain (figure 2) views the time domain from a 90-degree perspective. Amplitude is still in the vertical axis, but the horizontal axis is now the frequency. It makes no difference whether the time domain signal is a highly complex output from an accelerometer or a waveform obtained from a non-contact displacement as a series of sine waves.

To collect the spectra data from the machinery, the probe is attached to the surface of the equipment and the time-domain information is downloaded in the hand-held collection portion of the vibration analyzer. Note that the position of the probe relative to the equipment is important. In dealing with rotating machinery, vibration can occur in two primary directions, axial and radial. The radial direction can be further broken down into vertical and horizontal components. Because of the multidirectional vibration possibilities, measurements should be taken in all three directions.

Both experience and the type or use of the equipment dictates whether one or two directions need to be monitored to obtain adequate data. For example, a rotary pump might produce a displacement in the horizontal direction only due to the way it is mounted to its support structure. However, monitoring an additional axis is relatively simple and should be done whenever possible to ensure a complete analysis. When monitoring a piece of machinery for vibration, it is important to decide what points on the equipment need to be observed. In rotary equipment, most detectable problems

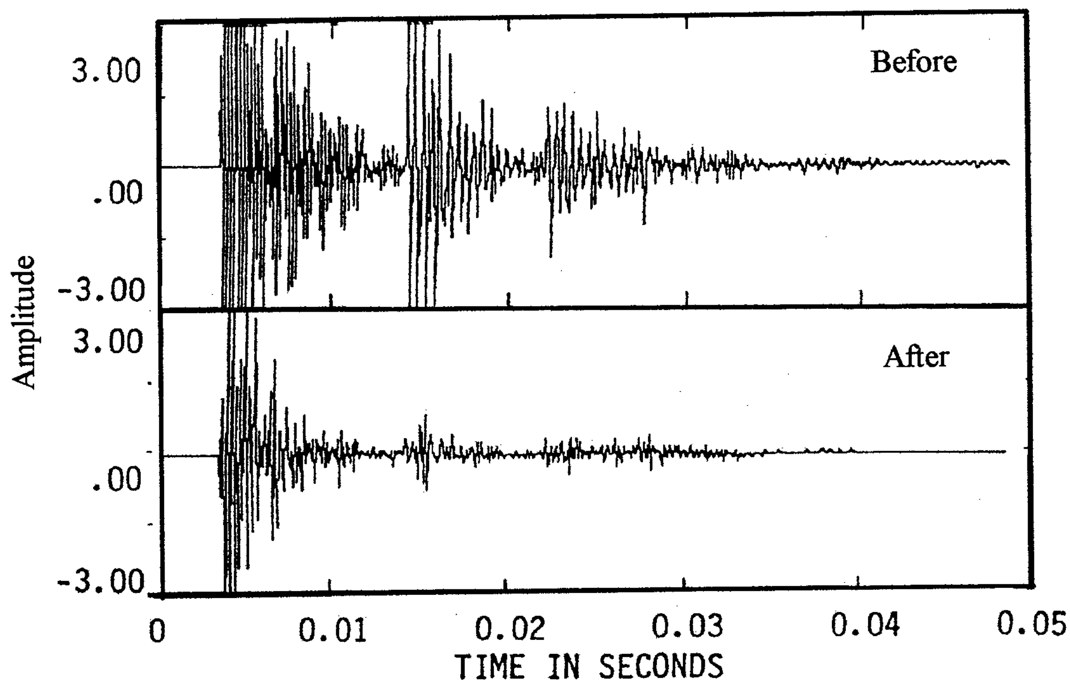

Figure 1 - Time Domain Chart

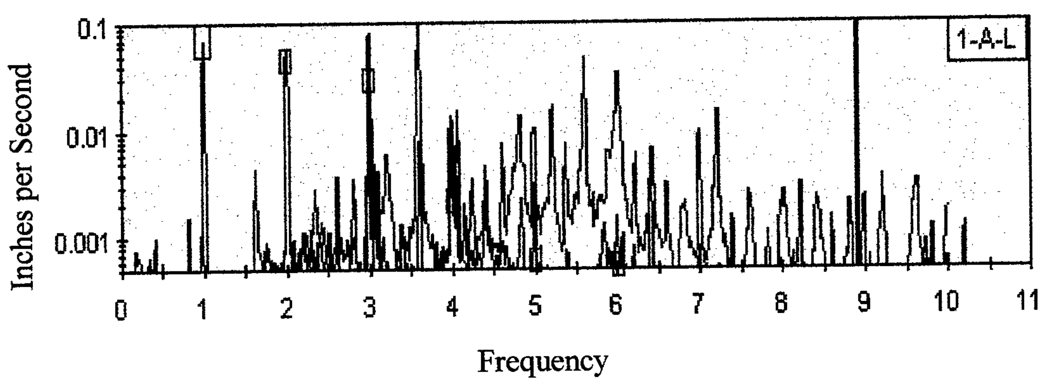

Figure 2 - Frequency Domain

occur in the shafts of rotors; thus, an obvious examination point is the bearing housing. Good bearing condition is essential for optimum performance of a machine, especially in equipment that operates at high speed. Bearing faults are the most common and easiest to detect faults found in equipment monitoring. To insure accurate spectrum analysis, measurements should be taken in the typical three locations to provide data in both axial and radial dimensions.

Typical faults in machinery that are detectable by routine vibration analysis include the following:

Imbalance
Misalignment
Bent or bowed shafts
Bearing faults of any nature
Structural degradation
Aerodynamic-related effects
Various coupling problems
Drive-related problems

To ensure consistency in data and to improve the effectiveness of the analysis, vibration data must always be collected from the machinery at or near the same point.

Equipment and Software

Vibration monitoring may either be done on a constant or periodic basis. The start up cost for a constant monitoring program is substantially more expensive and will require a longer payback period. Typically, facilities using constant monitoring cannot afford any breakdowns due to lost production. It is doubtful, that a constant monitoring program can be economically justified and there appears to be little additional benefit over implementing a periodic monitoring system. Therefore, this section will concentrate on portable equipment used for periodic monitoring programs.

Most non-industrial facilities with vibration monitoring programs use portable vibration monitoring and collection equipment for periodic monitoring. Such a program uses a hand-held data collector and vibration data are obtained from several points and then uploaded to a computer for analysis.

The first portable vibration monitor and collector was introduced in 1983. The unit was capable of measuring vibration with fast Fourier transform (FFT) analysis and featured automatic storage and transfer of measurements.

A typical vibration meter (figure 3) consists of a selectable amplitude range circuit, an integrator to transform the vibration signal from the pickup to velocity or displacement, and an AC-to-DC converter to change the signal to a DC value that can be read on the display. This same typical vibration meter is battery powered, uses a seismic pickup, displays the results on a liquid crystal display (LCD), and allows detailed analysis of unusual or suspect conditions before leaving the machine.

Figure 3 - Portable Vibration Meter

In addition, it will have provisions for measuring amplitude in either velocity or displacement units within several frequency ranges. Many data collectors also have an input for a phase reference, provisions for phase measurement, and auxiliary balancing capabilities.

The most common portable vibration meters have a display unit in a case with a separate sensor connected by 4 to 5 ft. of flexible cable. This arrangement makes it easy to use in confined locations and around obstructions.

There are three main types of vibration transducers: accelerometers, velocity transducers, and proximity probes. Using the proper sensor for your application is essential to obtaining quality data. Typically, the frequency of the equipment being surveyed will determine the proper transducer or pickup needed for data collection. As an example, rolling element bearings typically require a casing mounted sensor, and based upon frequency requirements, an accelerometer or a velocity transducer may be used. However, shaft movement or vibration is not reliably transferred to the outside casing due to the fluid film at the sleeve bearings or machine mass, so a proximity probe will provide a more reliable reading.

Accelerometers (figure 4) are the preferred motion sensors for most vibration monitoring applications. They are useful for measuring low to very high frequencies and are available in a wide variety of general purpose and application specific designs. The response of the piezoelectric accelerometer is unmatched for frequency and amplitude range. The piezoelectric sensor is versatile, reliable and the most popular vibration sensor for machinery monitoring.

Figure 4 – Accelerometers (Wilcoxon Research)

While the hardware collects the data and provides a graphical representation of the information, most significant problems could not be diagnosed in a timely fashion without the aid of spectrum analysis software. Software developers are very protective of their products and these products were largely unavailable for trial testing by the author. Only one operational demonstration program was reviewed. The ME'scope 4.0 by Vibrant Technology, Inc., was obtained and reviewed for this study. This program is designed for use with existing equipment and experimental modeling of new equipment. The software is offered on an annual lease for approximately $5,000. Technical support and file transfer format programs will cost an additional $1,500. This program would require additional training and would have to be operated by someone with above average technical and computer skills.

The computer program screens the incoming measurements to detect violations of preset criteria, which include the following:

- Overall measurements in violation of setpoints
- Frequency band and high resolution envelope (FFT spectrum, spectrum and time domain) violations
- Projected trends crossing an alarm setpoint within a given time period
- Percentage change from the previous measurement in excess of a predetermined value
- Statistical violations-mean plus standard deviation, in excess of a predetermined amount.

Trend analysis with condition monitoring software allows the computer to automatically recognize small but significant changes that would require a vast expenditure of time for the most skilled analysis. Most software systems provide an exception report which lists all measurements that are out of limits just minutes after the data has been loaded into the computer and analyzed by the software.

Implementation

Implementing a predictive maintenance program requires a sizable initial investment, but proper program management can recover this initial investment and allow continued annual savings. This has been repeatedly demonstrated throughout the industry, especially in the past eight years.

Several previous studies illustrate the feasibility of investing in a predictive maintenance program. One of these studies (Machinery Vibration Analysis 1990) showed that the cost savings of a predictive maintenance program versus a run-to-failure program will save most industrial facilities approximately $10/year/hp and recover the cost of implementation within the first year. The study also noted that the success of the program was expected to increase each year as technicians gain experience with the equipment and increase their accuracy in predicting component failure. In his 1989 study of maintenance costs for industrial rotating equipment, V.R. Dodd of Chevron Inc. measured run-to failure mode cost at $18 per horsepower per year, preventive maintenance at $13 per horsepower per year, and predictive maintenance at $8 per horsepower per year.

There were hundreds of testimonials available in articles, books, and Web pages echoing these levels of cost savings. These must be evaluated with some criticism because they were not independently verified. However, one aspect of the review of the publications did attract attention. Not one case was found expressing dissatisfaction or absence of cost savings by using vibration monitoring. Discussions on other conditioning monitoring systems showed at least one case of customer dissatisfaction with each program. Poor management of the program and lack of executive support in implementation explained most of these cases of dissatisfaction. These case studies show how an established predictive maintenance program can yield many cost benefits, including

- Preventing catastrophic equipment failures
- Increasing equipment on-line reliability
- Effectively scheduling of maintenance downtime
- Performing maintenance only when required
- Prioritizing and scheduling maintenance
- Reducing costs by eliminating emergency repairs
- Ensuring new equipment meets specifications at start up
- Ensuring all problems are corrected during warranty period
- Reducing spare parts inventory.

There are two options for implementing a vibration monitoring program. The program may be done by facility staff or through a separate contract. Almost all facilities with similar HVAC systems that were reviewed in other case studies began with a separate contract for critical equipment only. They gradually extended the scope of the program as they realized savings associated with the program and eventually trained their own maintenance personnel until they were able to perform the vibration monitoring program.

This gradual implementation by facilities is caused by two major issues: the substantial initial investment for a self performed program, and facility management's inability to convince executives of the anticipated cost savings from a vibration monitoring program. Implementing a program executed by facility maintenance personnel requires a substantial initial investment in both hardware and training. Hardware, software, and training of personnel can easily exceed $100,000 for the first year's costs. The majority of this cost will be in the wages and training of the technicians. The facility can not realistically expect a return on this investment until the second year when the technicians become proficient with the equipment and spectra analysis. The major cost savings from vibration monitoring are in cost avoidance of maintenance and impacts to the facility. Cost avoidance is subjective, difficult to prove, and assumed to be inflated to justify the program. It is difficult to prove a certain piece of equipment will breakdown sooner or will perform more efficiently with predictive maintenance. Some equipment may function very efficiently and trouble free without any maintenance. However, vibration monitoring targets the majority of machines that will develop problems and with proper use will find those machines that are developing problems before substantial damage occurs.

Facility managers' difficulty in convincing executives of the expected returns on this investment have resulted in them implementing vibration analysis contracts and documenting the savings over time. Facilities documenting returns on the cost of the contract greater than \$20:1 typically implement internally performed vibration programs within two years. Facilities experiencing moderate returns of \$10-20:\$1 typically perform some monitoring by staff, but continue to rely on external firms for periodic monitoring and trend analysis. Those facilities showing less than a \$10:1 return normally implemented only a partial vibration monitoring program and no monitoring was performed by the staff of the facilities.

Vibration monitoring allows precision alignment and balancing of machinery, which should result in decreased energy consumption. Energy savings are seldom identified by facility managers in justifying the use of vibration analysis; however, various references suggests a typical one to five percent amperage decrease after balancing and aligning rotating equipment. The cost savings to a typical three-phase motor can be calculated as follows:

$$\text{Power Savings} = [1.732 * (\text{Amp reduction}) * (\text{Voltage}) * (\text{Power Factor})]/1000$$

$$\text{Energy Savings} = \text{Power savings} * \text{Hours of operation} * \text{unit costs}$$

Reducing the instantaneous power consumption of one typical 25 horsepower induction motor rated at 460 volts/40 amps and a power factor of 0.9 by 1 amp (2.5 %) for 8000 hours per year can provide an annual cost savings of \$516 at \$0.08 per kWh.

An estimated $15,000 additional savings bonus for a facility using 30 comparable motors could offset a major portion of the labor or contract cost associated with a vibration monitoring program and increase the return on investment.

Vendors and Costs

There are numerous vendors of hardware and software equipment, however the majority of the hardware is manufactured by only a few companies. A list of vendors and addresses is supplied in the appendices. The most recognized names of vibration equipment and software are Bentley and Entek/IRD (Formerly International Research and Development Corporation). The majority of the companies offering vibration monitoring services use equipment manufactured by these two companies. There are numerous new software programs available and all appear to offer the same attributes.

Service contractors and consulting engineering firms that offer vibration monitoring and analysis exceed 100 and the number is growing quickly. Most organizations will start with a service contract for vibration monitoring until there are some actual savings to convince the customer the investment will be worthwhile. The cost of these services is extremely variable between companies.

CHAPTER 3
METHODOLOGY

Introduction

Is there a potential cost saving for using vibration monitoring as a predictive maintenance tool with HVAC equipment in USAF health care facilities? This study will analyze the potential benefits and methods of implementation. An eight-step process was used to research the feasibility and costs saving potential of vibration-monitoring and problems associated with implementing a predictive maintenance program. The steps taken were

Define the Problem
Gather Applicable Information
Determine Goals
Formulate Possible Levels of Implementation and Conclusions
Compare Data
Analyzing Results
State Conclusions
Make Recommendations

These steps are not specifically followed in the formulation of the report. Instead, a more succinct outline is used to present the information.

The USAF has defined the problem of insufficient maintenance and quality control many times in the past. Many facilities lack coordinated maintenance programs and the amount of reactive maintenance has been escalating over time. The USAF medical service has increased funding for PM (time based) programs over the last 5 years. They have also made an effort to improve the level of service provided by contractors and technicians through improved statements of work and providing more detailed requirements to facility level technicians. These have helped diminish the problem slightly, but overall, facilities are expending an excessive amount of funds on reactive (emergency) maintenance.

In the second step, discussions with USAF Medical Facilities Program Managers and individual facility managers provided an understanding of the USAF health care facilities current maintenance philosophy and applicable information related to maintenance costs and impact of HVAC system downtime. This step also included gathering information about the vibration-monitoring program at Shands Hospital, which was the model for comparative analysis. Shands was selected due to its convenient location and the fact that it was the only medical facility found within a reasonable travel distance which met the requirements of having used vibration analysis as part of its maintenance program for at least two years. Shands initially implemented vibration analysis in 1991, but only began using it as part of a predictive maintenance program in 1995.

The second step also required investigation of vibration monitoring as a predictive maintenance tool. A thorough literature search of current articles and companies from the Internet provided the information and contacts for obtaining this information. Tel-A-Train Incorporated, a company that specializes in maintenance training, provided their nine part video series used in their vibration monitoring certification course for review. This provided the background information of vibration monitoring procedures.

Concurrent with the initial literature review, there were numerous conversations with personnel from both the USAF and Shands to determine if there was similar information that could be used to perform a realistic comparative analysis to insure objectivity.

The next step was to perform the case studies on the actual expenditures by the USAF Medical Service and Shands Hospital, Gainesville, Florida on HVAC maintenance. The USAF and Shands have different tracking methods for financial and maintenance information that was not adequate for direct comparison. The cost and frequency of maintenance data were collected through questionnaires sent to all USAF medical facility managers and Shands' maintenance personnel. Being familiar with the USAF methods. only the specific information required from Shands for direct comparison was extracted from files and through interviews.

The fourth step was to determine the desired objectives of implementing a predictive maintenance program, prioritize them, and develop an accepted criterion for measuring the benefits of vibration monitoring.

The fifth step was to forecast possible conclusions associated with various levels of implementation. This was primarily based on the literature review and previous knowledge of the USAF health facilities maintenance program.

The sixth step was to compare the information gathered from the case studies and analyze the possible benefits the USAF health facilities could reasonably expect to achieve from implementing various levels of vibration monitoring.

The sixth through eighth steps were to analyze the comparisons, state conclusions and prepare recommendations on implementing vibration monitoring.

Development of Questionnaires

The development of the USAF questionnaire (Appendix A) was done based on a personal background knowledge of the Air Force Medical Service's documentation system and the pertinent information needed to perform a valid economic analysis of the potential for cost savings. The Air Force does not track detailed information on maintenance; therefore, the information requested was based on information that most experienced facility managers would be able to answer.

The Shands questionnaire (Appendix A) was developed after numerous discussions about their maintenance strategy and its execution. Shands tracks their maintenance history and the cost associated with equipment in a more detailed manner than the USAF. However, Shands also tracks their assets by different methods and they use a different classification system for the type of work performed on equipment. The questionnaire also addressed the reasons for wanting to implement vibration analysis and the benefits observed since implementation.

Performance of Case Studies

The USAF case study was accomplished through conversations and questionnaires with the officers assigned to the Air Force Medical Logistics Office – Facilities Management Division in Ft Detrick, Maryland, the Air Force Health Facilities Division, Brooks AFB, Texas, Headquarters Major Commands, and individual facilities at Air Force Bases throughout the world. Costs expenditures were obtained independently from three sources and compared for accuracy. All facilities that responded to having an emergency maintenance procedure that temporarily curtailed medical services were contacted for additional information to assess the indirect financial impact to the facility. The considerations for costs associated with the information obtained was compiled and sorted using an Access database and Excel spreadsheets.

The Shands Case Study was accomplished with the cooperation of their maintenance office and included detailed interviews with the managers and the maintenance staff. The study also included visual observation of the vibration monitoring data collection and balancing. Shands' historical data were entered into an Excel spreadsheet to allow comparison with the USAF data.

The main problem noted with compiling the case studies was the different methods of classifying maintenance work and the financial accounting of the work. Since the objective of this study is to justify implementation in USAF facilities, the Shands information and terminology was converted to the USAF methods and terminology in all comparisons.

Implementation Problems

Investigation of the problems associated with implementing a vibration monitoring program was restricted to the literature review and discussions with the facility maintenance staff at Shands Hospital. The Shands' program was studied in detail and it is gradually implementing vibration analysis into its total maintenance strategy. Most non-industrial facilities follow this type of pattern of implementation to determine the most cost-effective level of vibration monitoring. The Air Force Medical Logistics Office (AFMLO) Facilities Branch was consulted to determine the minimum requirements for implementing a condition monitoring system in USAF Medical Facilities.

CHAPTER 4
CASE STUDIES

The analysis of the maintenance cost of both the USAF Medical Facilities and Shands Hospital was restricted to HVAC rotating equipment. Most hospitals use built up air handling units (AHU) containing similar components. The equipment used in AHU at Shands is similar to those installed at USAF Facilities and sufficient for comparison.

USAF Medical Facilities

The USAF Medical Service maintains over 300 facilities totaling over 19,400,000 square feet of gross square footage at over 100 installations around the world. The USAF currently employs only a preventive maintenance (time based) program based on the manufacturer's recommendations for maintenance. Overall, the programs are averaging approximately $4 per gross square foot of facility for maintenance and repair. This cost is hard to define due to the ambiguities in the accounting systems at different locations. The only accurate costs for facility maintenance only costs were from those facilities under contract maintenance. Preventive maintenance standards are also better defined and implemented at facilities with contract maintenance. The overall costs per square foot varied negligibly between Civil Engineering Squadron (CES) and Contract performed maintenance. However, most facility managers rate the quality of service from contract maintenance to be slightly higher than identical services performed by the Civil Engineering Squadrons.

Surveys were sent to 45 major installations that had composite medical facilities or substantial stand alone outpatient clinics. Northern bases with very small cooling loads were not surveyed. Of these 45, 17 (38 %) responded with information adequate for analysis and the results are shown in figure 5. All the facilities that responded are of average size and provide general clinical services. No large hospitals comparable to Shands responded to the survey; however, information obtained from the two major commands includes the cost information of two large medical centers. Fourteen of seventeen facilities reported breakdowns in the last 3 years. Of these fourteen, ten reported multiple breakdowns. Only five breakdowns were reported that impacted medical services, but two of these were catastrophic failures that resulted in the temporary curtailment of services exceeding 3 days. The Air Force Medical Logistics Office (AFMLO) reports the total maintenance cost for all facilities in 1996 was $85,084.226. This number is known to have some capital improvement projects and they were estimated at 10% of the total expenditures based on a recommendation by the AFMLO facilities officers. The HVAC budget was estimated at 15% of the total maintenance budget based on an average of cost relationships reported by Shands and the International Facility Management Association (IFMA). Multiplying the reduced maintenance cost (Total – Capital improvements) of $76,575,803 by .15 provided the estimated annual mechanical maintenance cost of $11,486,371. This would equate to approximately $0.58 per square foot. This is a high cost per square foot, but considered feasible once the amount of emergency maintenance was determined.

The seventeen installations responding to the survey represented 2,523,894 square feet or 12.5% of total health care facility space for the USAF. Linear extrapolation of their data supplied for the mechanical budget for fiscal years of 1995, 1996, and 1997 provided an estimate of $4,006,900 total mechanical preventive maintenance cost for the last five years. The emergency maintenance costs reported for the five years was $2,502,000 and the total mechanical maintenance costs was $6,508,900. Roughly, 38.5% of the total expenditures were for emergency maintenance. Two of these facilities accounted for 75% of the total emergency repair costs. However, three of the facilities did not report any unscheduled maintenance. Projecting the reported square footage costs to the total USAF facility square footage provides an estimated $20,016, 000 cost of emergency repairs over the last 5 years or $4,004,000 per year. This is 34.85% of the survey's estimated total annual mechanical budget of $11,486,371.

Cost information was also obtained from two major commands, which are a headquarters operation for supervising the expenditures of a group of facilities, and analyzed to provide a secondary set of cost evaluations for comparison. This provided a quality check to strengthen the validity of any estimates made in the original calculations. The two major commands representing approximately 7,000,000 SF (35%) of the entire inventory reported spending over $3,500,000 on emergency HVAC repairs since 1993. If the median expenditure reported by Dohrmann and Alereza in 1986 (ASHRAE Applications Manual, 1995) a median expenditure of $0.24 per square foot for

Table 1. USAF Emergency Maintenance Survey Results

Facility	Gross SF	PM Costs FY97	Total Reported Repair Cost	
1	155,000	$40,000.00		$0.00
2	160,000	$12,100.00		$28,000.00
4	65,319	$17,500.00		$10,500.00
5	71,000	$3,000.00		$0.00
6	105,641	$22,000.00		$10,500.00
7	277,135	$178,900.00		$256,000.00
8	88,380	$20,000.00		$14,000.00
9	149,482	$10,000.00		$75,000.00
10	374,000	$46,000.00		$17,000.00
11	16,028	$2,000.00		$70,000.00
16	169,000	$55,000.00		$0.00
12	183,000	$160,000.00		$1,900,000.00
13	104,517	$22,880.00		$25,000.00
14	185,061	$45,000.00		$60,000.00
15	117,079	$33,000.00		$16,000.00
17	303,252	$134,000.00		$20,000.00
Totals	2,523,894	$801,380.00		$2,502,000.00
Total square feet of USAF medical facilities				19,486,312
Percentage of total inventory square feet in Survey				12.95
Total 1996 maintenance cost				85,084,226
10% reduction for capital improvements				76,575,803
15% of total cost for HVAC maintenance				11,486,371
Estimated 5 year total				57,431,853
Respondents Evaluation			**FULL**	**REDUCED**
Estimate 5 years of HVAC preventive maintenance			$4,006,900	
Total emergency maintenance			$2,502,000	
Allowance for 50% of breakdowns as unavoidable				$1,251,000
Total Maintenance			$6,508,900	$5,257,900
Percentage of emergency maintenance			38.44%	23.79%
Prorated estimated emergency cost by % SF extrapolation			$20,016,000	$10,008,000
Percentage of total mechanical maintenance cost			34.85%	17.43%

HVAC equipment maintenance. If this were converted to 1996 costs using standard present worth equations and a straight 4.5% annual inflation ($\$0.24 \times 1.045^{10}$), the cost factor would be \$0.373 per square foot. Using this cost factor, the mechanical maintenance budget of these facilities during that same period would be \$2,600,000 (7,000,000 x \$0.373). Comparison of these cost reveals that the facilities are spending approximately 57% (\$3.5M÷(\$3.5M + \$2.6M)) of the expected mechanical maintenance budget on emergency HVAC repairs. If this is typical of the entire USAF Medical Service, then approximately \$3,560,000 is spent on emergency maintenance of HVAC equipment every year. These two commands contained two facilities that experienced major repairs that can not be expected at every facility. However, records show that a major breakdown within the USAF Medical Service facilities has occurs at least once every three years.

Approximately 15% of the emergency cost were on equipment that was near or exceeded its life expectancy. These failures should have been anticipated and facility management scheduled the equipment for replacement. Even using a reduced number in the calculations, still leaves an estimated 30% of the total expenditures for emergency repairs.

The conservative approach of these calculations insures that these numbers are within a 10% margin of error against potential savings. Reducing the results to the lowest expected results of 20% still allows an anticipated improvement of 10-15% (\$1,000,000 to \$1,500,000) reduction in expenditures from implementing vibration analysis. These calculations prove the current USAF preventive maintenance strategy is not cost effective and must be replaced by a strategy that targets the reduction of emergency repair costs and improves the reliability and life expectancy of equipment.

Shands Hospital

Shands is a not-for-profit hospital occupying approximately 1,300,000 gross square feet. Approximately 150,000 square feet is combined mechanical and electrical service space. The facility was constructed in 1981 with additions and major renovations through 1990. The majority of critical HVAC equipment and those under vibration monitoring contract are approximately 8 to 10 years of age. Shands reports a yearly budget for maintenance of AHU equipment as approximately $170,000. This is approximately 40 % of their HVAC and five percent of their total maintenance expenditures. Both the overall maintenance costs and the HVAC maintenance cost are below industry averages. The primary goal of Shands' Predictive Maintenance Program (vibration analysis) is to identify impending problems with rotating equipment, such as fans, motors and pumps, before they turn into costly catastrophic failures and impact the clinical operations of the facility. There has been no reduction in the scheduled preventive maintenance program although they have reduced their expenditures over the last 5 years. Some of the reduction in expenditures is attributed to increased management efficiency, but the primary source of these savings is the reduction in repair cost and the increased productivity of technicians. The AHU technicians state the vibration monitoring helps them locate and correct problems with machinery more efficiently.

Vibration Monitoring began at Shands in 1991 with an engineering firm providing some analysis and service free of charge to allow the staff to see the benefits of a predictive maintenance system. A formal program of routine analysis began in 1995. Until that time, the VM was used to primarily to diagnose the problems in equipment. While this saved time and effort in locating the causes of problems, it was not realizing the full benefits of VM. Currently, approximately 45 pieces of equipment in the hospital and 15 pieces of equipment at the chiller plant are on the bi-monthly predictive maintenance inspection schedule. The majority of these pieces of equipment are part of the overall HVAC system. Tampa Armature Works (TAW) Engineering provides this service over a three day period at a cost of approximately $500/day. TAW breaks down the priority of their work based on four categories as described below from their statement of work performed:

Category #1- Most critical equipment including all chiller plant equipment.

All of this equipment will be checked during each inspection period unless the equipment is out of service and cannot be started. All high-speed fans that have experienced problems since the last inspection period will also be checked.

Category #2 – Supply fans of AHUs servicing critical areas.

Past history has shown that breakdowns most often occur on the higher speed units. For this reason. the fans of these AHUs as well as any other fans operating above 1800 rpm will be analyzed.

Category #3 – Lower speed units.

Lower speed units such as return fans, exhaust fans, and units serving less critical areas have not had a history of problems and have a lower priority.

Category #4 – Any other lower speed units including pumps and fans that have a history of relative trouble free operation.

The vibration monitoring follows the basic guidelines described in most texts. TAW's general description of their work is as follows:

The first day - recording and analyzing the vibration levels on all of the equipment in categories #1 and #2. If time permits some of the equipment in categories # 3 and # will be checked.

The second day - making any repairs or adjustments needed based on the analysis of the vibration levels taken on day #1. Repairs included balancing of fans or sheaves, coupling alignment of motors and pumps or motors and gearboxes, or any other repairs that Shands personal were not trained to perform.

The third day – Time remaining on day three is spent checking the vibration levels on any equipment in categories # 3 and # 4 that were not checked on day # 1 or other equipment Shands' personnel believe may be developing a problem.

Work orders are written on all problems identified as needing specialized services to correct them (i.e. bad belts, worn sheaves, damaged bearings, loose bolts, etc.) to ensure Shands personal make the necessary correction and repairs.

A prime example of the benefits of VM was observed on 7 February 1998. Based on initial vibration levels taken by Shands' mechanics, a non-scheduled service call was initiated for TAW Engineering to check two fan units that were registering excessive vibration. On 7 February 1998, a TAW technician investigated the source of the vibration. The technician used an IRD 885 "Mechanalysis" portable vibration monitor with a velocity probe pickup and a strobe light. The initial vibration levels of the first unit were oscillating from 10 to 14 mils. After adding balance weights, vibration readings did not correspond to the expected levels. The fan unit was siting on a spring isolation base that was providing some resonance readings on the time domain graph. The belts were removed and the motor was balanced from 2.9 mils to .75 mils. The belts were reattached and a stabilizer rod was added to the framework of the fan to reduce vibration. The fan was balanced to approximately 2.5 mils by adding clip on weights to the four fan blades. The total time for the investigation and balancing was approximately two hours. An additional hour was spent manufacturing and installing the stabilizer rod.

The second unit had recently experienced an increase in vibration from less than two mils displacement to over four mils displacement. While four mils was still within the limitations of the equipment, this increase happened very quickly. The initial readings at the time of the investigation were oscillating between 12 and 21 mils in both the horizontal and vertical directions. The technician noticed that the shroud and turning vanes on both sides of the fan were damaged. The fan was shut down and the access doors were removed for physical inspection. Removal of the access panels confirmed the technicians suspicions that minor damage to the fan had already occurred. Several welds to the fan blades had already separated. The maintenance supervisor was informed of the damage and the TAW recommended that the fan remain out of service until the fan could be repaired. In discussing this occurrence with the Shands supervisor and the TAW technician, it was estimated that the fan could have failed within the next 72 hours. This fan is part of a parallel system with each fan capable of supporting approximately 75% of the load. This unit was down for approximately one week and while no clinical services were impacted, there was a substantial increase in complaints. This unit serves the cystology operating suite among other areas. This area must maintain strict airflow requirements to continue operating. In order to provide adequate air to the suite, dampers had to be closed and air diverted from clinical and administrative areas. An cost estimate for accomplishing this, answering complaints, and resetting the system was based on 4 mechanics spending 4 hours per day for 3 days times labor costs of $16/hour (wage and benefits). An indirect labor cost for maintenance personnel associated with this failure is $864. Combined with the possible loss productivity of staff occupying these areas, a conservative estimate of loss is $1500. Luckily, this outage occurred at a time when the outside air temperature was a moderate 50-55 degrees and the temperature could be moderately controlled or productivity losses could have been higher. If the unit had not been shutdown and had failed, it would have caused extensive damage to other equipment within the distribution system, resulting in a catastrophic failure of the system. Failure of the system would have resulted in cancellation of surgeries, loss productivity of high salary individuals, lowered morale, and patient's lower perception of quality of medical care. If you address these items of cost avoidance as savings, then the amount of savings accumulated between the two scenarios easily justifies the total yearly investment by Shands in Vibration Monitoring.

The experience confirms that while technology can provide an abundance of information, if the personnel are not trained, or do not have the experience, then the information cannot be effectively utilized.

Shands' maintenance staff fully supports the vibration monitoring program and believes the program should be expanded to be used on additional equipment and to provide trend analysis for critical equipment. However, they are experiencing difficulty in convincing management of the total benefits achieved.

Trend analysis would be beneficial in establishing the life expectancy of the HVAC equipment. Considering the current age of the majority of the HVAC equipment, (8-10 years) this could be beneficial in targeting equipment for planned replacement over the next five years and would recoup the additional cost of approximately $2,000 per year cost with only one avoidance of equipment failure. Don Glaser also noted that there were problems with the equipment within the first two years that had could be associated with excessive vibration. It is his belief that many of these problems could have been avoided if they had been balanced using vibration analysis during installation and prior to the end of the warranty period.

CHAPTER 5
RESULTS AND DISCUSSION

Introduction

Reliability of HVAC systems is an essential element in maintaining a healthy healing environment. HVAC related issues accounted for five of the top ten occupant complaints in a recent survey conducted by the International Facility Manager's Association. (November 1997, Indoor Environment Review)

A survey of 30 USAF Medical Service Corps Officers echoed that reliability and performance of equipment was the number one concern and the primary reason for preventive maintenance. The participants were asked to rate the level of importance of reliability, performance, cost, durability, maintainability, and space requirements separately between 1 (low) to 20 (high). The results from the 28 respondents are reported in Table 2.

Table 2. Essential Elements of Mechanical Systems

	Average	Standard Deviation
Reliability	18.07	3.42
Performance	17.75	2.37
Cost	14.14	5.32
Durability	12.86	3.74
Maintainability	12.93	4.51
Space Required	8.25	4.94

The results show that the administrators rated cost considerably lower than reliability or performance. Performance was the most consistent answer and was high on every response. These results were discussed with facility managers, designers, and engineers and they were not what were expected. The expected results by these personnel were that cost and performance would be rated above reliability. Facility managers have been using cost reduction as the basis for justifying the increase in preventive maintenance and have seldom discussed the reliability of the system. Applying the results as a value engineering analysis, we should concentrate our expenditures in maintenance on aspects that increases the reliability and performance of the system. Both of these are primary targets of vibration monitoring.

Recently, members of the American Society for Hospital Engineers (ASHE) performed a survey to determine the proper staffing levels for maintenance departments in facilities. This was an attempt to address the lack of reliability in equipment and failures to prevent breakdowns and outages of equipment and services by justifying additional personnel to perform preventive maintenance. While they do address the problem, additional staffing only addresses the symptoms and does not consider searching for the root cause of failures. The bathtub curve (figure 5) illustrates that some time driven maintenance will actually increase your chances of failure. Maintenance records generally show that equipment malfunctions are high after installation and near the end of their life expectancy. Equipment that is provided routine maintenance follows this same trend between maintenance periods. Using vibration monitoring tools during he critical time periods alone should reduce the number of failures considerably.

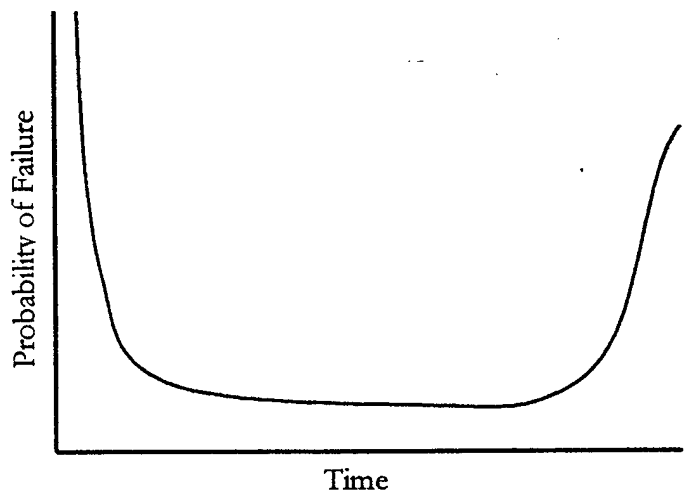

Figure 5 - Bathtub Curve

An additional benefit of vibration monitoring is that it provides quantitative data that will allow facility managers without the mechanical background to provide quality assurance of preventive maintenance. Trend analysis from vibration data would be extremely hard to forge and will show if preventive maintenance is being performed.

Comparative Analysis

Internal comparison of data provided by each subject showed that the USAF has been slightly increasing their expenditures per square foot for maintenance each year, while Shands has been reducing their expenditures per square foot. The accuracy of the cost data provided by Shands could not be specifically verified; however, the reported costs are within the expected cost range for medical facilities as reported in the IFMA 1997 *Benchmarks III, Research Report #18.* Shands' maintenance cost of $2.00 per gross square foot is also below the 25-percentile benchmark of $2.15 established by MECON, a hospital benchmarking service. Even these reports have a notable variance as pointed out by Don Glaser, Shands' Director of Facility Operations. Almost every facility reports some items differently. Some facilities may report minor upgrades to HVAC systems under maintenance. Some facilities like Shands may purchase chilled water (Shands purchases approximately 20%) and not report any associated maintenance costs. Isolating the air handling units for comparison, Shands has shown a reduction of 21% (figure 6) or approximately $36,000 in total expenditures on this equipment.

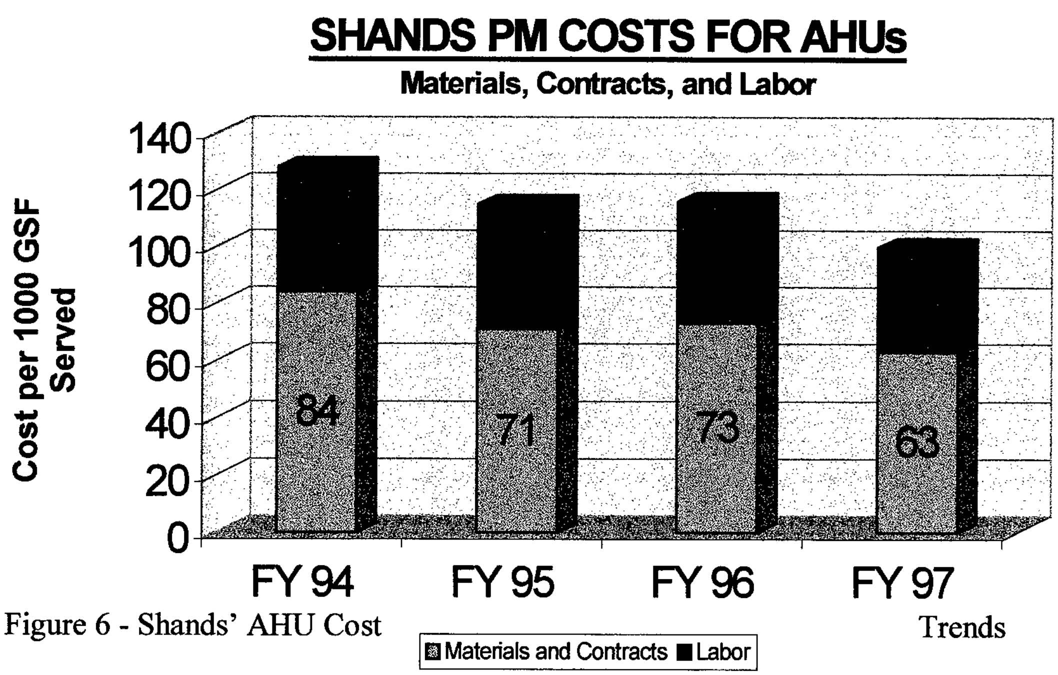

Figure 6 - Shands' AHU Cost Trends

Shands personnel attribute most of these savings to the vibration monitoring program and the reduction in emergency maintenance.

In contrast, USAF Medical Facilities are showing an increase in cost expenditures for the same level of maintenance. This is primarily due to the different levels of emergency maintenance. The results of the USAF survey revealed that the USAF is spending 30 to 38% of their mechanical maintenance budget on emergency maintenance. Two of the seventeen facilities responding accounted for approximately 75% of the total emergency maintenance cost, but four facilities also reported no emergency maintenance. The average cost per square foot of emergency maintenance reported multiplied by the total USAF inventory showed that this was approximately 34% of the total mechanical budget. Prorating the total maintenance cost to the square footage of the survey facilities provided an average expected cost of $55,092,000 (85,084,226 * 12.95% of facilities * 5 years) of total maintenance for these facilities for the last three years. The total reported expenditures of $2,502,000 for HVAC emergency maintenance is approximately 4.5% of the total expected maintenance costs of these same facilities.

In 1994, prior to full implementation of vibration analysis, Shands was reporting a similar cost per square foot for AHU Maintenance as the 1997 estimates shown for the USAF. Shands is reporting a substantial reduction in AHU maintenance costs over the last 3 years with only one failure. The cost savings associated with maintenance alone have been approximately $31,000 per year. The cost of vibration monitoring associated with the AHUs is approximately $10,000. The vibration monitoring system has provided approximately 3 to 1 return on investment.

Accurate AHU maintenance cost could not be derived from data provided by the USAF. Analysis of Shands 1996 final maintenance budget showed that their total expenditures on HVAC equipment maintenance was approximately $420,000 or approximately $0.32 per square foot and 14.8% of their total maintenance cost. This is comparable to the 15% or $0.57 per square foot for HVAC) used in the USAF calculations and supports the conclusion that the Shands maintenance program savings are comparable to what the USAF can expect if they implement vibration analysis in their medical facilities.

Table 3. Comparative Maintenance Costs of Case Studies

	Total HVAC Costs	Reactive Maint. Costs	% Reactive	Cost/SF
USAF	$11,486,371	$4,003,200	34.85%	$0.57
Shands	$420,000	$20,000	4.75%	$0.32

Calculating the potential savings from implementing vibration analysis forces us to establish some standards for considering cost avoidance. The following table is one scenario based on numbers established within this study and the relative savings pointed out in reduced impact to the facility. The scenario is based on a $1,000,000 base investment and a first year maintenance cost of $100,000. An arbitrary life cycle of 25 years was taken for this calculation with small scale failures occurring at ten and twenty years. The cost associated includes direct and indirect cost associated with the failures. Since the predictive method will provide advance notice of the failure, the repairs will be scheduled and the indirect cost reduced approximately 95%. The cost for the predictive maintenance repair was therefore assigned as 10% of the estimated cost of the status quo method. The costs assigned for the comparison are shown in table 4. These cost are very conservative and are only used to show the total potential for cost savings by implementing a predictive maintenance strategy.

Table 4. Comparative Analysis of Expected USAF Maintenance Cost for HVAC Equipment

	Status Quo PM	**Predictive Maintenance**
Annual		
Baseline	100,000	100,000
Increased Annual Cost (VM)	0	10,000
Premature Parts Failure	17,000	5,000
Increased Maintenance Costs	3,000	1,000
Energy Consumption 1	15,000	0
Sub total	135,000	116,000
Cost per Lifecycle 2		
Loss Services from Shutdowns	50,000	5,000
Decreased Life Span Value 3	40,000	0
Loss Productivity	25,000	2,500
Sub total	115,000	7,500
25 Year Lifecycle Present Worth	2,505,902	2,046,937

1. *From this study, based on one amp reduction per motor on 30 motors.*
2. *Outages with impact to facility operations are calculated at 10 and 20 year mark.*
3. *1,000,000 equipment depreciated by straight line method over 25 years and estimating a 1 year (4%) increase in life expectancy.*
4. *See Table 5 for calculations*

Calculating the life cycle cost of these over a 25 year life span (see figure 11) shows vibration monitoring and predictive maintenance can reduce the present worth of the system and its performance by \$458,965. The present worth of the implementation cost was calculated as \$184,244. This would provide an approximate return on investment of 2.5 to 1. This is a conservative result for an average sized facility and the case studies reviewed in the literature review reported significantly higher returns. Implementing vibration monitoring in the 78 major facilities will provide a substantial savings valued at over \$35,000,000 in lifecycle cost.

Table 5 Comparative Present Worth of USAF Taintenance Strategies

	ITEM: HVAC Maintenance Life Cycle Period: 25 Yrs Date: 16 Mar 98	Original: Estim Cost	Status Quo Pres Worth	Alternative 1: Estim Cost	Pred. Maint. Pres Worth
Initial Costs	Base Cost	1,000,000	1,000,000	1,000,000	1,000,000
	Interface Costs	0	0	0	0
	Total Initial	1,000,000	1,000,000	1,000,000	1,000,000
Repair and Replacement	Emergency Repair Impact Cost 3 % interest				
	a. Year 10 PW factor 0.7441	75,000	55,807	7,500	5,581
	b. Year 20 PW factor 0.5537	75,000	41,526	7,500	4,153
	Reduced Lifecycle (1 year) PW factor 0.4776	40,000	19,104	0	0
	Total Repairs and Replacement Cost		116,437		9,733
Annual Costs and Income	Annual Cost 3 % Annual Increase				
	a. Preventive Maintenance Escalation Rate: 0 PW factor 17.4131	100,000	1,741,315	100,000	1,741,315
	b. Vibration Analysis Escalation Rate: 0.5 PW factor 18.4244	0	0	10,000	184,244
	c. Premature Failures Escalation Rate: 0.5 PW factor 18.4244	17,000	313,214	5,000	92,122
	d. Decreased Energy Efficiency Escalation Rate: 0.5 PW factor 18.4244	15,000	276,366	0	0
	e. Increased Maintenance Costs Escalation Rate: 1 PW factor 19.5235	3,000	58,570	1,000	19,523
	Total Annual		2,389,465		2,037,204
	Total Present Worth Costs		**3,505,902**		**3,046,937**

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Research Conclusions

The US Air Force Medical Service and all medical facilities could benefit from the use of vibration analysis to monitor heating, ventilation, and air conditioning (HVAC) equipment. Periodic vibration analysis is inexpensive and easy to implement. A Predictive maintenance program is essential to ensure HVAC equipment continues to operate efficiently and reliably and vibration analysis is a vital component. Vibration analysis can assist the maintenance staff in locating problems that cause abnormal vibrations and correct the problem before damage or failure. The analysis in the study show that vibration monitoring can provide enough cost savings in energy efficiency and reduced maintenance expense to recover the cost of implementation. Therefore, there is no financial risk in implementing a predictive maintenance program with vibration analysis. These savings are small compared to the cost avoidance associated with failure of equipment. The greatest benefit of using predictive maintenance techniques comes from cost avoidance of downtime in the facility. The reduction in lost time, comfort, productivity, and medical services as well as the avoidance of potential lawsuits from poor IAQ associated with infection control are major considerations for medical facilities in determining what maintenance strategy to employ. Condition monitoring reduces the risk of these occurrences and saves money through cost avoidance. The savings through cost avoidance are difficult to quantify and are always challenged.

Vibration monitoring is an industry proven tool for reducing the cost of preventive and emergency maintenance. Most healthcare facility mangers are not completely convinced of the total reliability of vibration monitoring and have not reduced their levels of preventive maintenance. Effective use of vibration analysis to ensure efficient performance of equipment can also reduce the energy cost of the facility. Most facilities can expect the savings from these two items to equal or exceed the cost of implementing a vibration-monitoring program.

The USAF Medical Service must make a paradigm shift in their maintenance strategy. Their facilities are prime candidates for the use of a proactive maintenance strategy using a form of condition monitoring. This study shows that a proactive maintenance strategy consisting of vibration monitoring, preventive maintenance, and trend analysis will increase maintenance efficiency, ensure the quality of the indoor environment, and minimize infection risks to patients and staff.

Vibration Monitoring of critical HVAC equipment will provide both a direct and indirect return on investment. All facilities with contract maintenance should add this requirement to the contract's scope of work. There are many firms offering this service throughout the country and monthly monitoring of an average facility could be estimated at approximately $500 per day for 18 days per year. This would mean an increase in approximately $9,000 for data collection and another $2,000 for trend analysis and reporting for this level of service. If the system saves one piece of equipment or prevents one outage in 5 years, this will more than pay for its cost.

The USAF medical service should spend less than 5% of their mechanical maintenance budget on reactive maintenance. However, their expenditures on emergency maintenance reported from the survey results are estimated at over 34% of the USAF Medical Service's mechanical budget and over 12% of the mechanical budget for a median sized average sized medical facility. Many of these facilities are serviced by on-base government agencies, which do not charge premium prices for most emergency services. If they did, the costs associated with their emergency maintenance would be substantially higher.

If half of the emergency costs reported were unavoidable (age or defective parts) and removed from consideration, the cost available for reduction by vibration monitoring would be lowered by approximately $2,000,000 or 17% of the total yearly mechanical expenditures. If vibration monitoring only reduces this percentage of emergency maintenance costs by a conservative 5 percentage points (17% to 12%) per year, it will be saving an estimated $622,000. The estimated cost of implementing a contract vibration monitoring system for the entire inventory of the 78 major facilities would be approximately $1,000.000 ($12,500 per facility). If the reduction were increased to, 10% (17% to 7%), then the savings would exceed $1.200,000. Effective implementation and management of a vibration program at selected facilities could provide significant savings and the program will pay for itself with the cost savings resulting from reduced emergency maintenance. Energy savings, reduced preventive maintenance costs, improved risk management of the indoor environment, and diminished impact of outages on medical operations are all additional benefits that will add to the justification and return on investment.

Validity of Data

The data compared in this study are based on historical data that comes from different accounting and tracking methods. Determination of the actual numbers being compared required some interpolation of data and assumptions of exactly what type of work was done. When interpolation was required, the most conservative approach that would not favor implementation of vibration monitoring was taken. The USAF study data are very broad based and the study assumes that the reported data are factual and accurately documented. The actual costs of maintenance for different facilities were widely divergent. However, the reported trends in the increased amounts of both preventive and reactive maintenance performed by individual facility managers, provides validity to the recommendation for condition monitoring. Comparison of data reported by the bases to the data reported by the major commands showed the same trends. The most significant result of the survey analysis is that the USAF medical service has at least $1,200,000 of annual mechanical maintenance expenditures that can potentially be eliminated.

Recommendations for Implementation

This study recommends the USAF Medical Service implement a predictive maintenance strategy using vibration monitoring to monitor equipment condition. The requirement to perform vibration monitoring and trend analysis should be added to the statement of work of maintenance contracts at hospitals. The estimated cost of this additional service will be less than $20,000 for the largest facility and $11,000 for an average facility. Providing an additional contract to facilities being serviced by CES will be less beneficial due to the time lag for service. Unless they can be convinced to implement a vibration monitoring program across the entire installation, it will be difficult to document actual cost savings. To ensure the quality of service, the USAF medical service's facility management class should include an approximately two hour block on vibration monitoring. An orientation of essential concepts required to provide quality assurance capability and the benefits derived from the program must be provided to insure successful implementation.

Recommendations for Further Study

Recognizing the benefits of a proactive maintenance strategy is difficult without financial justification. This study has shows that vibration analysis can pay for itself with increased energy efficiency and maintenance productivity. This study also shows that there is a potential for significant savings in cost avoidance associated with equipment failures, but the amount of savings can not be objectively determined without obtaining more extensive data on USAF facilities.

This study will be presented to the USAF Medical Logistics Office with the recommendations that vibration analysis be immediately implemented at all facilities with contract maintenance. Vibration analysis will also be recommended for inclusion in the testing and certification of equipment prior to facility acceptance on major construction projects and be repeated prior to the warranty expiration.

The facility managers do not need to know the details of vibration analysis, but they will need an orientation on how it works and what they should expect from the vibration analysis contractor. If the USAF implements vibration analysis, the USAF medical facility managers training course at Sheppard AFB, Texas should add a 4 hour training period on vibration analysis and predictive maintenance. The interactive training programs and video tapes provided by Tel-A-Train, Inc., provide an excellent resource to orient facility managers on the process and what to expect from the vibration analysis contract.

It is recommend that this study be continued by implementing vibration monitoring at three USAF health care facilities for a minimum of three years to further determine the actual level of savings that can be obtained. All facilities should have a documented preventive maintenance program and an accurate accounting of maintenance and performance of levels of individual equipment for the last three years. This is essential to establish trends for comparison and removing subjectivity from the study. Additionally, the government agencies supervising the study must decide the following aspects of the program.

Determine the specific objectives (e.g. reliability) and how to measure them.

Establish standards for measuring the value of each intangible component that impacts the operation of the facility.

Determine the data collection and analysis procedures

Determine how cost avoidance will be calculated.

Determine the potential for cost savings prior to implementation

Set a specific period for analyzing and reporting benefits.

Determine the technical qualification for personnel involved.

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APPENDIX A
SURVEY QUESTIONAIRES

MEDICAL FACILITIES MAINTENANCE SURVEY

I am Captain Jon Yow and I am a Health Facilities Officer currently in a masters program at the University of Florida. I am working on assessing alternative maintenance strategies and I am developing a thesis on "Feasibility of Vibration Analysis as a Predictive Maintenance Tool on Heating, Ventilation, and Air Conditioning (HVAC) Equipment in U.S. Air Force Medical Facilities.

I would like for each of you to take some time and fill out the information below. Please be as accurate as possible. The information below will allow cost comparison to determine if Vibration Analysis will save money. Life Cycle Costing is looking for a payback of initial investment over 3 years. Please provide the requested data or as much as possible on your main hospital or clinic building.

Request your response by 19 December 1997 to jonyow@nersp.nerdc.ufl.edu.

Facility :
Year Constructed:
Gross Square Footage:
Maintenance by Contract, In-house, or CES:
Number of full time personnel assigned to FM:
Number of personnel assigned full time to Maintenance:
Cooling Capacity: ____ Tons/BTUs of cooling (Can be estimated at 1.25 x 1 chiller)
Preventive (Scheduled) Maintenance costs associated with HVAC Systems:

FY 95: ______ FY 96: ______ FY 97: ______

Any Non-scheduled replacement or repair of HVAC components in Last 5 years:
(failures of chillers, motors, shafts, fans, etc.)

Component: Age of component if known:
Direct Repair/Replacement Costs: Down time of machinery: (hours or days)
Reason for failure if known:
Was scheduled maintenance performed on the component as required: (yes or no)
Major problems associated with downtime: (Comfort, lost productivity, temporary cancellation of services, etc.)
Did Maintenance warn you of possible breakdown: (yes or no)

Facility Point of Contact: Phone Number: e-mail address:

Thank you in advance and again you can reach me at:

Jonyow@nersp.nerdc.ufl.edu Phone 352-335-5802 (call anytime)

Jon Yow
3800 SW 34th Street, Apt H-66
Gainesville, Florida

SHANDS

VIBRATION MONITORING QUESTIONNAIRE

When was Shands constructed? 1983

When did you begin VM services? 1991 random services/1995 Predictive Program

Was anyone within the organization experienced with active condition monitoring systems prior to initiating the investigation to implement one? NO

Vibration Analysis was recommended by pneumatic contractor.

What key aspects caused you to decide on Vibration Analysis?

VM contractor came into the facility and did sampling showing the benefits and potential for cost savings.

Did you consider any other methods of "Condition Monitoring"? (Which ones) Yes

Bearing temperature monitoring and Oil analysis.

Did you do any Life Cycle Cost analysis to determine the economic benefit?
If so, what was the time for pay back of initial installation?

No. The initial reason for implementation was to reduce or eliminate catastrophic failures. Reduction in any maintenance was considered an extra benefit.

Did you use VM on a sample of equipment for a trial period first, or go directly to total installation. Yes.

Machinery with a record of problems and breakdowns. Mostly equipment operating at over 3000 rpm.

Did you initiate the installation and advertise for VM services or did a vendor approach you first?

Vendor did free sampling to show benefits after inquiries from Shands.

How did you decide on TAW engineering (Current Contractor)for your VM requirements?

The initial service engineers from 1991 were hired by TAW. Shands had been very satisfied with their service. The quality of service degraded after their departure. Shands solicited TAW to take over the VM Service Contract.

SHANDS

VIBRATION MONITORING QUESTIONNAIRE

Approximate costs of maintenance for equipment being monitored before implementation of Vibration Monitoring (VM)?
$166,000

What are the current costs for maintenance of equipment that are being monitored?

$130,000 (including VM costs)

What is the Scope of Work for the Vibration Monitoring Services?

From TAW Scope of Work

Has staff increased or decreased? Increased by 1 additional person

Before:	7 (4 for PM)	3 for (WO)
Now:	8 (PM/WO)	Only 2 primarily associated with AHU maintenance and VM Monitored Equipment

Do you have anyone on staff trained as a vibration monitor? (If so how many)

Yes. 1 fully trained and 2 trained on basic skills.

During the 3 years before implementation of VM, how many (estimate) breakdowns (unexpected) of equipment did Shands experience?

Few. The first recorded breakdowns occurred in 1990-1991. This can be partially explained by the relatively new age of the equipment (1983). VM was implemented as a result of recognizing the potential for future breakdowns.

Did these cause any downtime that affected services? If so, what were the ramifications ($$, productivity, morale). Yes

What Department: Laboratory, Cysto, OP clinics
What Problems: Equipment, productivity, specimens, etc.

SHANDS

VIBRATION MONITORING QUESTIONNAIRE

Since the implementation of VM, how many breakdowns (unexpected) has Shands experienced?

1 - this year – Down Time 1 ½ weeks.
Majority of unconfirmed breakdowns were high speed (>3000 rpm) machinery.

Some shutdowns such as SF 18-2 have occurred but they were due to discoveries by VM that prevented a more expansive problem from occuring

What were the estimated annual maintenance expenditures for Shands on HVAC equipment now monitored prior to implementing VM?

AHU Equipment	
Total:	166,000
HVAC Preventive:	91,000, (55% (Est)
HVAC Reactionary:	75,000 (45)%

What were the estimated annual expenditures for Shands on monitored HVAC Maintenance after implementing VM?

AHU Equipment		
Total:	130,000	
HVAC Preventive:	110,500	85% (Est)
HVAC Reactionary:	19,500	15%

What would you estimate is the $ savings in direct costs for using VM at Shands?

Estimate the full 36,000 can be attributed to VM. The capability of not increasing due to inflation can be attributed to other programs implemented within the maintenance shop.

Have you reduced the amount of Preventive Maintenance performed?

No. The VM services is used mainly to discover problems with machinery early and prevent catastrophic breakdowns which disrupt services.

Are you considering expanding the use of "Vibration Monitoring" to the use of other equipment?

Currently there are no plans to expand the services as a program to any other equipment. There is an ongoing expansion of the current services to other mechanical equipment that is experiencing problems or breakdowns

SHANDS

VIBRATION MONITORING QUESTIONNAIRE

What aspect of the VM as utilized by Shands would you like to see improved?

More equipment monitored like Pumps, and all other rotating equipment
Increase scope for more monitoring and eventually continuous monitoring.
Trend Analysis for Proactive Maintenance Program.

What percentage of Chilled Water is bought?

20% over the entire year.

Rate the following aspects of Mechanical Equipment in order of importance.
1 is lowest – 20 highest

Maintainability	18
Cost	14
Reliability	20
Performance	20
Durability	20
Size/Space	12

GENERAL SHANDS DATA:

Verbal Description of Shands: Shands Medical Center is a not for Profit Health care facility offering outpatient and inpatient services including: Surgical, Obstetrics, Transplants, and various clinical services

Total SF: 1,300,000 SF
MECH SF: 200,000 SF (Approximate)
HVAC SF: 150,000 SF (approximate)

Total Maintenance Staff: 51
Mechanical: N/A
HVAC: 8
AHU: 1 FTE

APPENDIX B
VIBRATION MONITORING VENDORS

VIBRATION MONITORING VENDORS

Vendor	Address
Applied Reliability, Incorporated	11944 Justice Ave., Suite E Baton Rouge, LA 70816
Bently Nevada	Bently Nevada Corporation 1617 Water St., P.O. Box 157 Minden, NV 89423
Bruel & Kjaer CMS	Bruel & Kjaer 799 Roosevelt Road. Suite 311 Glen Ellyn, IL 60137
BW/IP International, Inc.	Byron Jackson Products – Pump Division P.O. Box 2017, Terminal Annex Los Angeles, CA 90051
C.J. Analytical Engineering, Inc.	C.J. Analytical Engineering, Inc. R.R.1, Box 353 Francisco, IN 47649
Computational Systems, Inc. (CSI)	CSI 835 Innovation Drive Knoxville, TN 37932
Data Signal Systems, Inc.	Data Signal Systems, Inc. P.O. Box 1608 Friendswood, TX 77546
DLI Engineering Corporation	DLI engineering Corp. 253 Winslow Way West Bainbridge Island, WA 98110
ENDEVCO Corporation	ENDEVCO Corporation 30700 Rancho Viejo Road San Juan Capaistrano, CA 92675
Engineering Dynamics Incorporated	Engineering Dynamic Incorporated 16117 University Oak San Antonio, TX 78249
ENTEK-IRD	Entek Scientific Corporation 4480 Lake Forest Drive, Suite 316 Cincinnati, OH 45242
Ono Sokki Technology, Inc.	Ono Sokki Technology, Inc. 2171 Executive Drive, Suite 400 Addison, IL 60101
PCB Piezoelectronica, Inc.	PCB Piezoelectronics, Inc. 3424 Walden Avenue Depew, NY 14043-2495
PMC/Beta Corporation	PMC/ Beta Corporation 4 Tech Circle Natick, MA 01760
Predict/DLI	Predict/DLI 253 Winslow Way West Bainbridge Island. WA 98110

VIBRATION MONITORING VENDORS

Vendor	Address
Schenck Corporation	Schneck Corporation 535 Acorn Street Deer Park, NY 11729
SKF Condition Monitoring	SKF Condition Monitoring 4141 Ruffin Road San Diego, CA 92123
Technology for Energy Corporation	Technology for Energy Corporation P.O. Box 22996 Knoxville, TN 37933-0996
VCI	VCI 5733 South Dale Mabry Hwy. Tampa, FL 33611
Vibra-Metrics, Inc.	Vibra-Metrics, Inc. 1014 Sherman Ave Hamden, CT 06514
Vibra-Tech, Inc.	Vibra-Tech 1201 North Ave. H Freeport, Texas 77541
Vibration Specialty Corporation (VSC)	Vibration Specialty Corporation 100 Geiger Road Philadelphia, PA 19115
Vitec	Vitec 23600 Mercantile Road Cleveland, OH 44122
Walker Associates	Walker Associates P.O. Box 58224 Webster, TX 77598
Wilcoxon Research, Inc.	Wilcoxon Research, Inc. 21 Firstfield Road Gaithersburg, MD 20878

BIOGRAPHICAL SKETCH

Jon Yow graduated from Tennessee State University (TSU) in August 1986 with a Bachelor of Science in Architectural Engineering. At TSU, he was selected as the most outstanding architectural engineering student for both his sophomore and senior classes.

Following graduation he was commissioned as an officer by the United State Air Force and worked as a project manager for the Air Force Surgeon General's Facilities Division supervising the planning, programming, design, construction, and maintenance of Air Force medical facilities. He has worked with facilities across the U.S., in Japan, and in Korea.

In 1995, Captain Yow was competitively selected by the Air Force to attend graduate school. He selected the University of Florida's M.E. Rinker Sr. School of Building Construction and entered the graduate program in the Fall of 1996. Captain Yow expects to graduate in Spring 1998 and will continue employment with the U.S. Air Force as a Medical Facilities Liaison assigned to HQ Air Force Civil Engineering, Pentagon, Washington D.C.

Captain Yow is currently a member of The National Fire Protection Association (NFPA), Health Care Section, Health Facility Institute (HFI), American Society of Hospital Engineers (ASHE), International Facility Manager's Association (IFMA), American Society of Heating Refrigeration and Air Conditioning (ASHRAE), and the Vibration Institute.